SUPERPAVE GYRATORY COMPACTION REQUIREMENTS FOR FAA'S HOT MIX ASPHALT SPECIFICATION

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PRESENTED FOR THE
2010 FAA WORLDWIDE AIRPORT TECHNOLOGY TRANSFER CONFERENCE
Atlantic City, New Jersey, USA

April 2010

ACKNOWLEDGMENT

The work described in this paper was supported by the FAA Airport Technology Research and Development Branch, Manager, Dr. Satish K. Agrawal. The contents of the paper reflect the views of the authors who are responsible for the facts and accuracy of the data presented within. The contents do not necessarily reflect the official views and policies of the FAA. The paper does not constitute a standard, specification, or regulation

ABSTRACT

Superpave mix design technology for hot mix asphalt (HMA) is commonly used by the highway industry; however, HMA mix design methods for civil airport pavements are still based on the Marshall method, as included in FAA's P-401 specification. With the shift in the industry away from the Marshall methods, the equipment and expertise required for the Marshall designs are becoming less common. As a result, it has become necessary for the FAA to establish their specifications and mix design methods on Superpave methods using the Superpave Gyratory Compactor (SGC). For the Superpave methods to produce results and performance equivalent to the Marshall method, the volumetric mix properties must be established at a requisite number of gyrations. The primary focus of the first phase of this research, which is the subject of this paper, is to establish the number of gyrations needed to produce mixes with volumetric properties (e.g., air voids, VMA and VFA) equivalent to well performing Marshall mixes. An equivalent compaction level of 70 gyrations is proposed to replace the 75 blow Marshall compaction method in the FAA's P401 specification. Phase II of this research, currently underway, will compare the performance of mixes designed using these two compaction methods.

INTRODUCTION

The purpose of this paper is to present results for ongoing research sponsored by the Federal Aviation Administration (FAA) on the relationship between 75-blow Marshall compaction and Superpave gyratory compaction when designing HMA airfield pavement mixes following the FAA's P401 specification. This research was broken down into two distinct phases. In Phase I—now complete—the average or typical number of gyrations required to provide similar volumetrics to 75-blow Marshall compaction for a range of good-performing airfield pavement mixes was to be determined. In Phase II, performance testing on mixes designed using both Marshall compaction and gyratory compaction is to be performed to determine if the different compaction methods affect typical performance levels as estimated using laboratory tests. This paper focuses on the results of the Phase I research. There were three primary objectives for Phase I of this project:

- Establish guidance for the recommendation of N_{design} for the gyratory compactor using Marshall mix design proportions for FAA specification *P-401 Hot Mix Asphalt* currently required by FAA Item P-401 in Advisory Circular 150/5370-10B.
- Establish specifications for designing asphalt mixes using the Superpave Gyratory compactor that provide performance equivalent to that provided by the specifications for the Marshall compactor mix designs.

- Run verification testing on a variety of HMA mixes.

In the sections below, the results of the Phase I research are summarized. This includes a discussion of the materials used in the research, the experimental methods and the experiments performed. The results are summarized and discussed, and conclusions and recommendations are presented. An important aspect of these recommendations is the plans for Phase II of this research project.

MATERIALS, METHODS AND EXPERIMENT DESIGN

Tables 1 and 2 below summarize the materials used in the research. A total of eight mixes were used; seven of these have been used in pavements at different airport facilities and have good records of performance. The only mix not used in an airport facility is the NAPTF mix, which was included in the study because it has been extensively used and well documented in research performed at the National Airport Pavement Test Facility near Atlantic City, NJ. These eight mixes include a wide range of aggregate types, aggregate sizes and original binder grades. Volumetric data from the job mix formulas (JMFs) for the mixes are summarized in Table 2.

Table 1.
Mixes Used in Phase I Test Plan.

Mix Name/ Code	Airport	Aggregate Type	FAA Maximum Aggregate Size	Original Binder Grade
JFK93	JKF, New York	Gneiss	19 mm	AC 20
JFK97	JFK, New York	Dolomite	25 mm	PG 82-22
JFK96	JFK, New York	Dolomite/ granite gneiss	25 mm	PG 82-22
ACY	Atlantic City (ACY)	Basalt	19 mm	PG 64-22
LEX	Lexington, KY (LEX)	Limestone	19 mm	PG 70-22
ELM	Elmira, NY (ELM)	Crushed gravel	25 mm	PG 64-28
NAPTF	National Airport Pavement Test Facility, Atlantic City, NJ (NAPTF)	Argillite	19 mm	PG 64-22
CHO	Charlottesville (CHO)	Diabase	25 mm	PG 64-22

In determining the number of gyrations equivalent to 75-blow Marshall compaction (referred to as "N-equivalent"), the following general approach was used:

1. Verify the original mix design using 75-blow Marshall compaction
2. Using the verified Marshall mix design, prepare gyratory specimens using 75, 100 and either 50 or 125 gyrations, depending on the results of the compaction with 75 and 100 gyrations.
3. Plot air voids as a function of gyrations, and estimate N-equivalent as the number of gyrations providing the same air void content as the verified Marshall mix design.

Table 2.
JMF Volumetric Data for the Mixes.

Mix Name/ Code	**Asphalt Content** Wt. %	**Air Void Content** Vol. %	**VMA** Vol. %
JFK93	5.2	3.9	16.3
JFK97	4.7	4.0	15.2
JFK96	4.7	4.0	15.4
ACY	5.0	3.5	15.7
LEX	5.7	3.8	15.7
ELM	5.8	3.4	14.0 Min.
NAPTF	5.2	3.5	15.7
CHO	5.2	3.2	16.7

N-equivalent was determined in this way for three different binders for most of the mixes: a PG 64-22 binder, a PG 76-22 binder modified with SBS polymer, and a PG 76-22 binder modified with polyethylene (Novophalt). In some cases, only the PG 64-22 binder was used in determining N-equivalent.

In order to examine the variability in the verified Marshall designs and in N-equivalent, this work was performed at two laboratories: Advanced Asphalt Technologies, LLC (AAT), in Sterling, VA, and Soiltek, Inc., in Rutgers, NJ. Each laboratory independently verified the Marshall designs and then determined the value of N-equivalent. As an example of the procedure used to determine N-equivalent, Figure 1 shows gyrations plotted as a function of compacted air voids for the second replicate of the Atlantic City mix design, as evaluated at AAT's laboratory. In this example, the value for N-equivalent was found to be 49 gyrations. Note that a log transformation was used in relating gyrations to air void content; this was found to give the best results in most cases.

There are three independent variables in the experiment design: mix (eight levels), binder (three levels) and laboratory (two levels). The dependent variable is N-equivalent. All N-equivalent values were determined in replicate, and to ensure that these replications were as independent as possible, the second set of determinations of N-equivalent was not done until the first set had been completed. In analyzing the results, graphical methods and analysis of variance were used. In analyzing the data, laboratory was considered a fixed effect, while mix type was considered a random effect. This means that that the conclusions are in this case meant to apply to only these two specific laboratories, but to a wide range of mixtures—not just the eight included in this study.

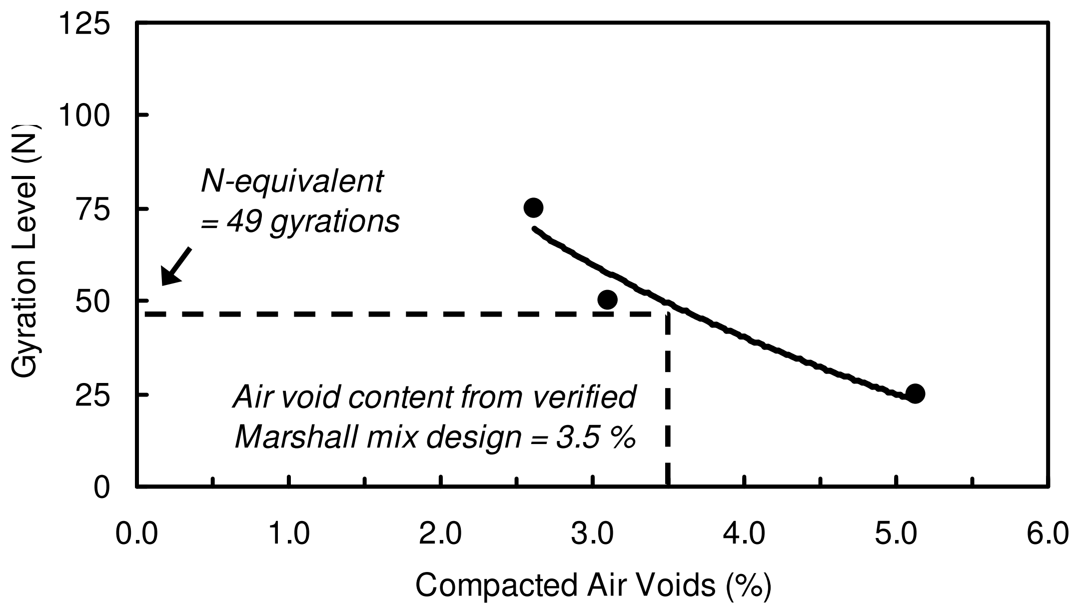

Figure 1. Determination of N-equivalent for the Second Replicate of the Atlantic City Mix Design, as Evaluated in AAT's Laboratory.

RESULTS

Figure 2 shows the results of the N-equivalent experiment. The coding used in the horizontal axis is as follows. There are three codes separated by a slash. The first code represents the mix (see Tables 1 and 2). The second code represents the binder: PG64 represents the PG 64-22 binder; SBS represents the PG 76-22, SBS modified binder; and NOV represents the PG 76-22, polyethylene modified binder (Novophalt). The third code represents the laboratory which determined the value of N-equivalent: AAT represents Advanced Asphalt Technologies, LLC, and ST represents Soiltek. The plot includes two-standard deviation error bars, representing the pooled or average standard deviation for the entire data set. It is clear that there are significant differences in the values of N-equivalent, both among mixes and between laboratories. It is not clear from this plot if there are significant differences in N-equivalent among the three asphalt binders.

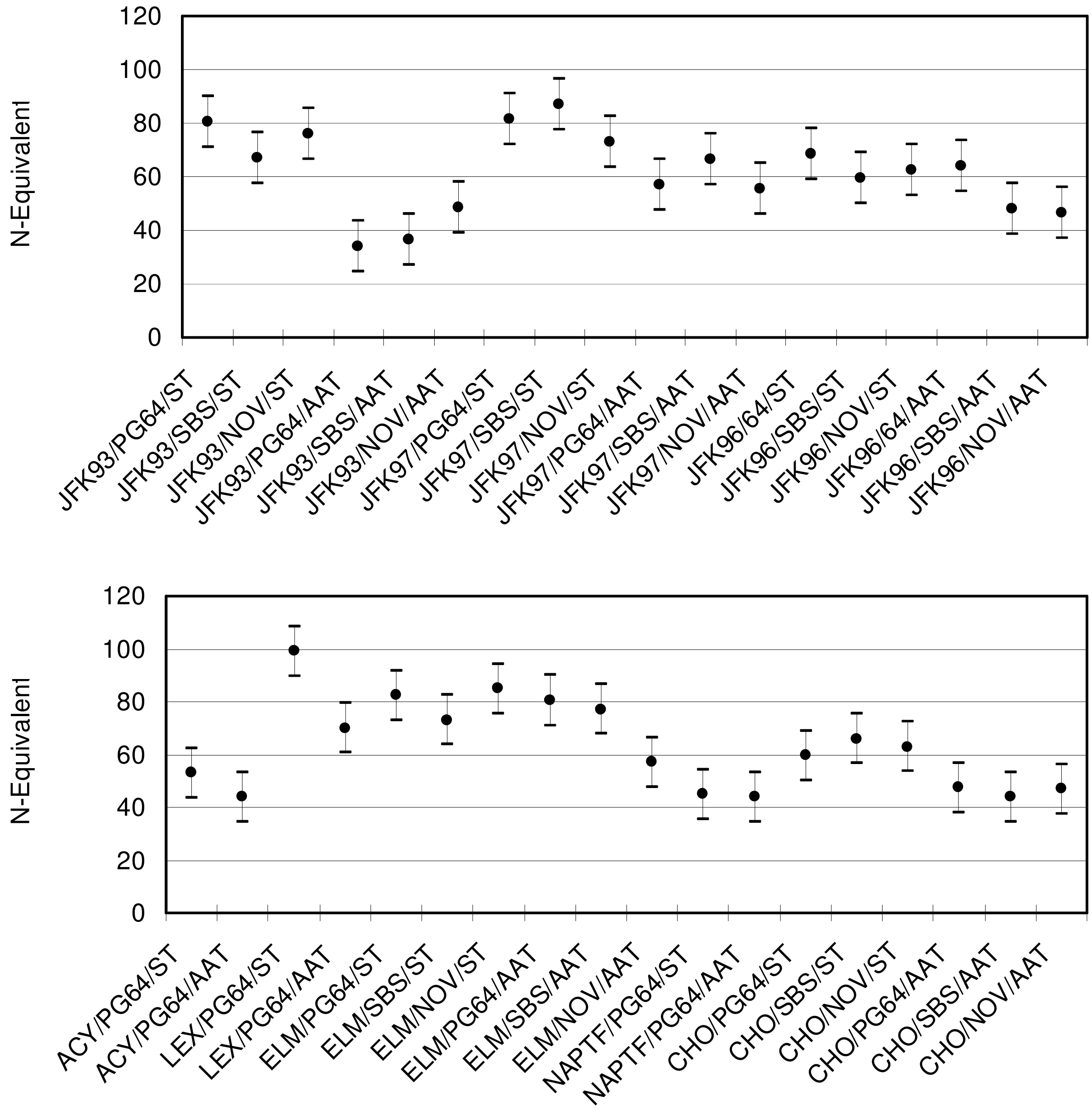

Figure 2. Plot of N-Equivalent Values; *Error bars show pooled ±2 standard deviation limits for the average value of N-equivalent.*

To confirm that mix and laboratory were indeed statistically significant factors, and to evaluate whether or not binder grade was a significant factor in predicting the value of N-equivalent, an analysis of variance was performed on the data. Laboratory and binder grade were treated as fixed effects, while mix type was treated as a random effect. Both asphalt content and design air void content were included as covariates, since it was felt that the level of these variables might affect the value of N-equivalent. The only significant predictors were laboratory ($p = 0.001$) and mix type ($p < 0.001$). Asphalt content and binder grade both had an insignificant effect on N-equivalent ($p = 0.625$ and 0.505, respectively). The effect of air voids was marginal (p = 0.162). The overall average value of N-equivalent was found to be 62. Thus, this analysis suggests that the typical number of gyrations required to provide compaction similar to 75-blow Marshall compaction, for good-performing HMA airfield pavement mixes, is 62. However, there is significant variability in N-equivalent among mixes and also between the two laboratories included in this study.

DISCUSSION

Two other research projects have recently been conducted which included a determination of N-equivalent values in a manner similar to what was done in this project. Cooley et al. determined an average value for N-equivalent of 49 for 10 different mixes originally designed using 75-blow Marshall compaction [2]. It should however be noted that Cooley et al. ultimately recommended design gyrations values of 50, 65 and 80, depending upon the tire pressure for the design aircraft. Rushing has reported an N-equivalent value of 69 (rounded to 70), based on research performed at the U.S. Army Engineer Research and Development Center (ERDC) [2]. Thus the value determined here of 62 gyrations falls in between the values determined in the two other recent projects examining this issue. Because the ERDC study was more substantial, and because it was felt that a difference of less than 10 gyrations was not practically significant, it is recommended here to follow ERDCs recommendation that 70 gyrations should be used in designing HMA for airfield pavements, in order to provide typical compaction levels similar to that achieved using 75-blow Marshall compaction.

To better understand the significance of using 70 gyrations as a standard, the asphalt contents of the eight mixtures were estimated at this level of compaction for both laboratories. The results are summarized in Table 3. By using a constant value of 70 gyrations for N-equivalent, much of the difference between the two laboratories was removed. This is because the primary cause of differences in N-equivalent between the two laboratories was differences in the asphalt contents of some mixes during Marshall verification. It should be noted that the average asphalt contents at 70 gyrations for both laboratories are somewhat higher than the average asphalt content for the JMFs. However, the materials used in this study were not exactly the same as those used in the original mixes, which may have caused slight differences in the compaction properties of the mixtures.

Table 3.
Average Asphalt Contents by Laboratory Using Varying

Laboratory	**Average Asphalt Content Using Varying Values of N-Equivalent** Wt. %	**Average Asphalt Content Using a Constant Value of N-Equivalent of 70 Gyrations** Wt. %
AAT	5.42	5.43
Soiltek	5.74	5.55
JMF	5.15	

To further examine the differences in asphalt contents at 70 gyrations as compared to those of the JMFs, Figures 3(a) and 3(b) are presented, which are simply bar charts of the asphalt contents for the different mixes and laboratories as estimated at 70 gyrations. Also included in these charts are the JMF asphalt contents. It is clear that the asphalt contents for the two laboratories are quite similar for the different mixes, and in general slightly higher than the JMF asphalt contents. However, there is still much variability between the mixes, although in this case that variability is expressed in terms of binder content rather than in terms of N-equivalent.

An important question now becomes how will these observed differences in the behavior of these mixes under the different compaction procedures might affect performance, if at all. To understand this problem, the design procedure must be clearly understood. In implementing gyratory compaction with an N-design value of 70, many current HMA mixes designed using FAA procedures probably will not change—the aggregate gradation and binder content will remain the same, while still providing proper levels of air voids and VMA. However, for some mixes, the binder content may have to be adjusted upwards or downwards in order to meet FAA requirements. In some cases—probably a limited number—changing the asphalt content alone may not produce a mix meeting FAA requirements. In such situations, the aggregate gradation will have to be modified to obtain an acceptable mix. The question then becomes, what will the overall performance level be in the mixes designed using gyratory compaction compared to that of the mixes designed using Marshall compaction? A related and perhaps more important question is how does the variability in performance compare for mixes designed using the different compaction methods?

Phase II of this research is now underway to answer these questions. In this second part of the research, most of the mixes included in Phase I will be subjected to performance testing. One additional mix—with documented performance issues (excessive rutting)—has also been included. The mixes will be designed using both 75-blow Marshall compaction and 70-gryation compaction, following all pertinent FAA specifications. In some cases, the gyratory designs will be different for the two laboratories; in others, the designs will be essentially identical. The two sets of mixes—Marshall and gyratory—will then be subjected to a variety of performance tests to determine if there are significant differences in performance as measured in laboratory tests.

CONCLUSIONS AND RECOMMENDATIONS

Based upon the results of Phase I of this study, it is concluded that the typical level of gyratory compaction required to provide a compaction level equivalent to that of 75-blow Marshall compaction, for good-performing HMA airfield mixes, is 62 gyrations. Differences in the value of N-equivalent were observed between the two laboratories included in this study. However, it was found that this difference was largely due to differences in the asphalt contents of the verified Marshall designs for the two laboratories, and because of differences in gyratory compaction between the laboratories. In order to maintain consistency with recommendations of similar research by ERDC, it is recommended that the standard level of gyratory compaction used to design HMA for airfield pavements be set at 70 gyrations.

Significant differences in N-equivalent were observed between the eight mixtures included in this study. It is therefore possible that using gyratory compaction to prepare HMA mixes for airfield pavements might result in differences in overall performance and/or variability in performance compared to mixes designed using 75-blow Marshall compaction. A second phase of research is now underway to investigate performance of HMA mixes designed using gyratory compaction and as designed using Marshall compaction using laboratory tests.

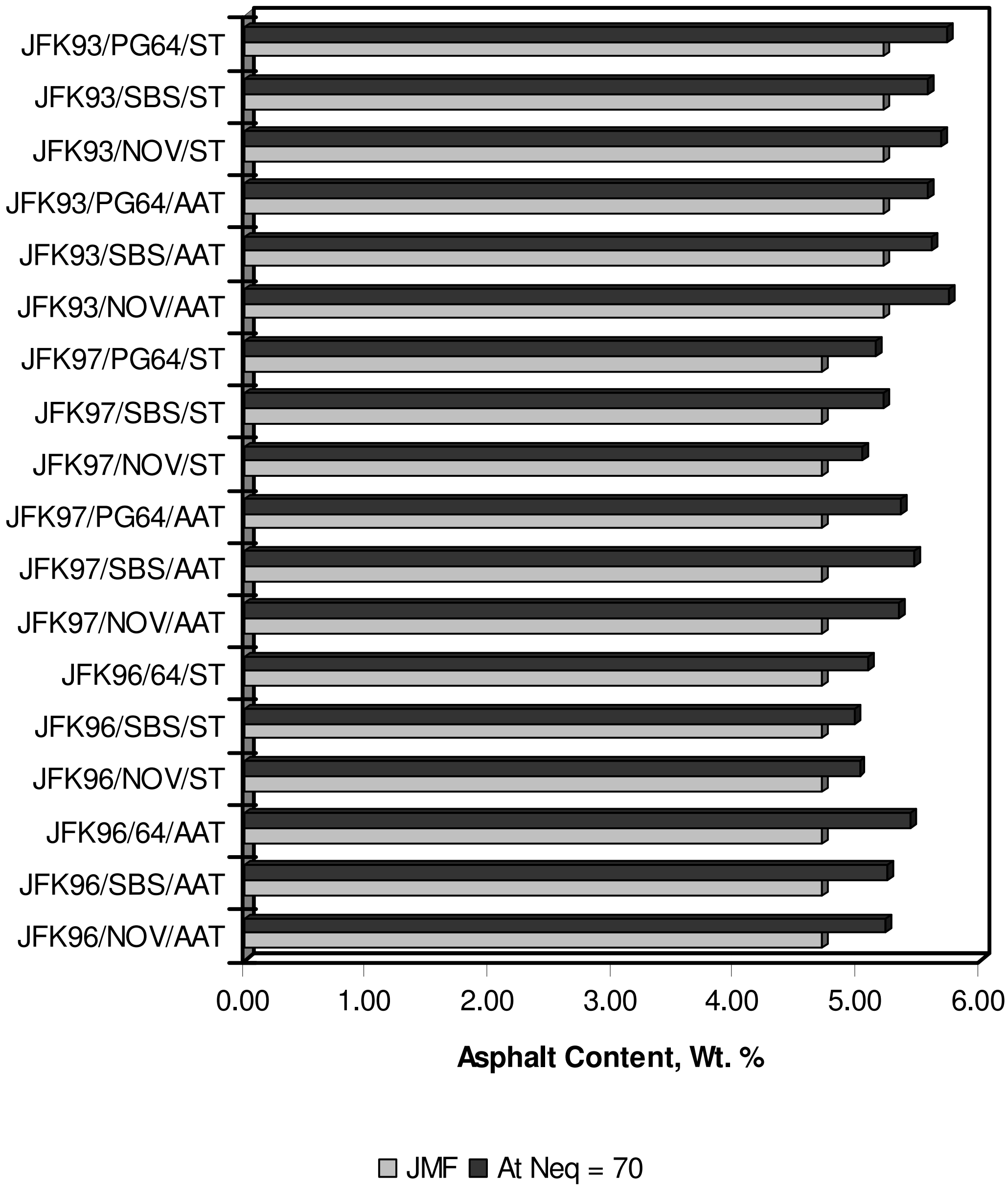

Figure 3(a). Asphalt Contents for Different Mixes and Laboratories at 70 Gyrations Compared to JMF Asphalt Contents (part 2).

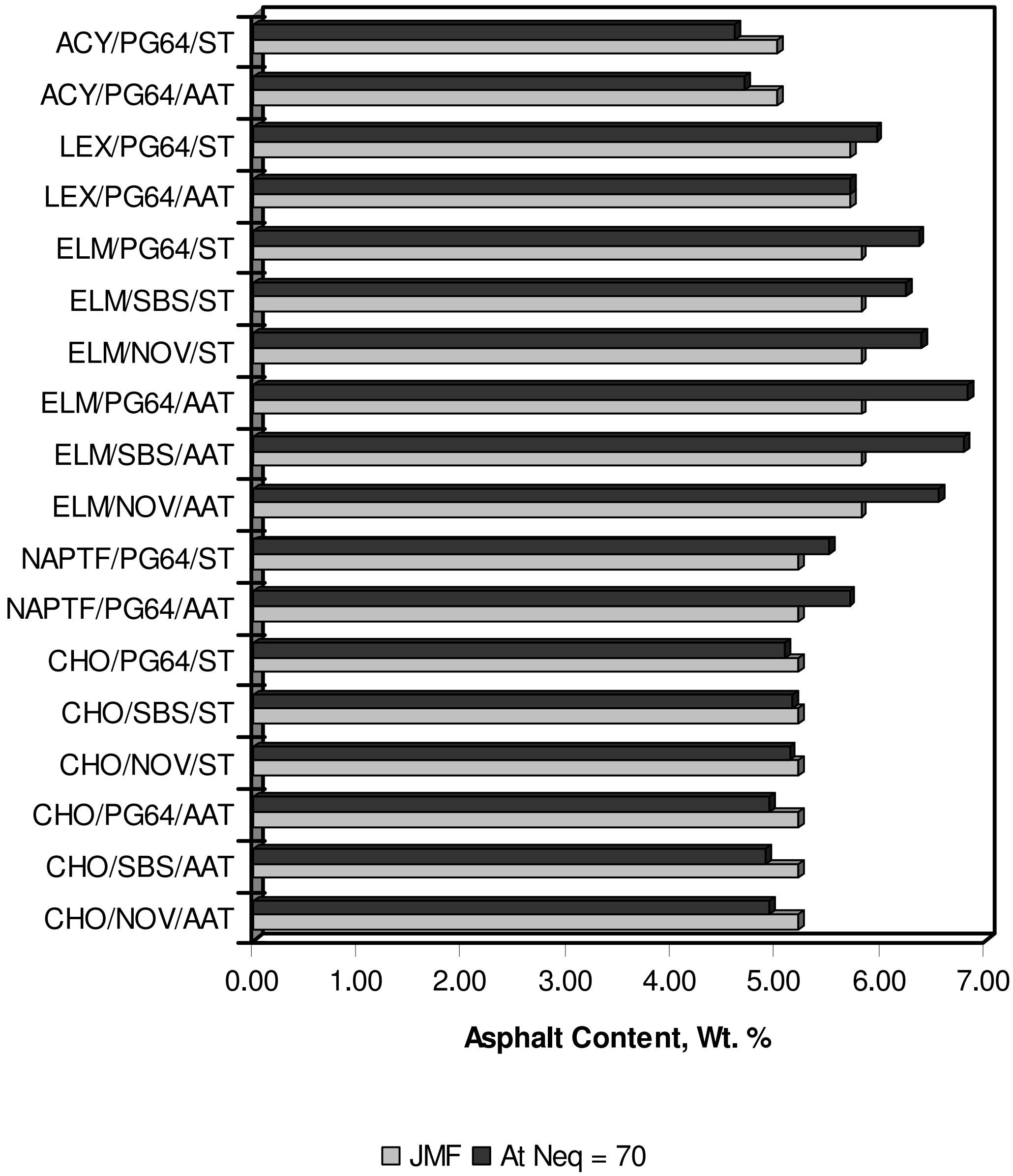

Figure 3(b). Asphalt Contents for Different Mixes and Laboratories at 70 Gyrations Compared to JMF Asphalt Contents (part 2).

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